In-Band and Out-of-Band Emissions from Charge-Selected Sn Ions

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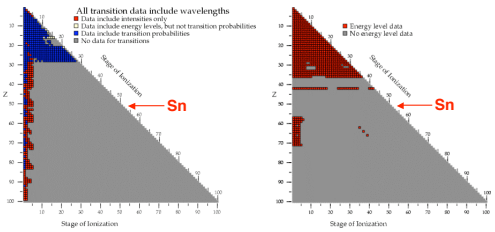
How is the present status of atomic data ?

Spectroscopic data, namely transition wavelengths, transition probabilities, and energy levels of atoms in each ionic states, is very far from complete for the heavy elements such as Sn (Z = 50).



Elements and ionization stages for which the NIST Atomic Spectra Database contains data of transitions and energy levels.

http://physics.nist.gov/

What can we do for EUVL as atomic physicists ?

Development of EUV light sources for Lithography required spectroscopic data of multiply charged Sn ions. Hence, we measured EUV emission spectra from the individual charge states of Sn ions in charge transfer collisions with neutral gas targets to provide spectroscopic data.

$$Sn^{q+} + T \rightarrow Sn^{(q-c)+*} + T^{r+} + (r\text{-}c)e^-$$

$$\downarrow \text{ photon emission}$$

$$Sn^{(q-c)+}$$

T : gas target atom

Principle of the charge exchange spectroscopy. The number of captured electron c is generally uinity.

Setup for In-Band measurement

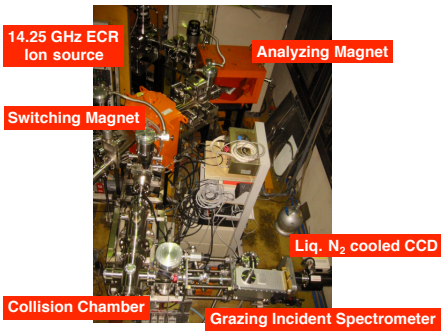
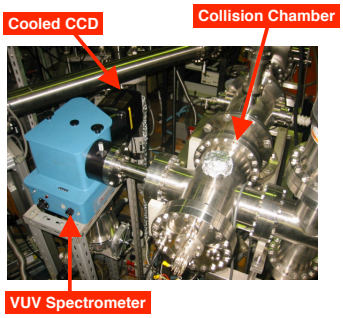
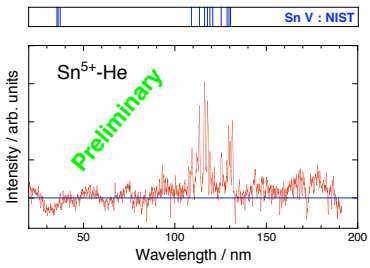


Photo of the experimental setup. Multiply charged ion facilities in Tokyo Metropolitan University.

Setup for Out-of-Band measurement



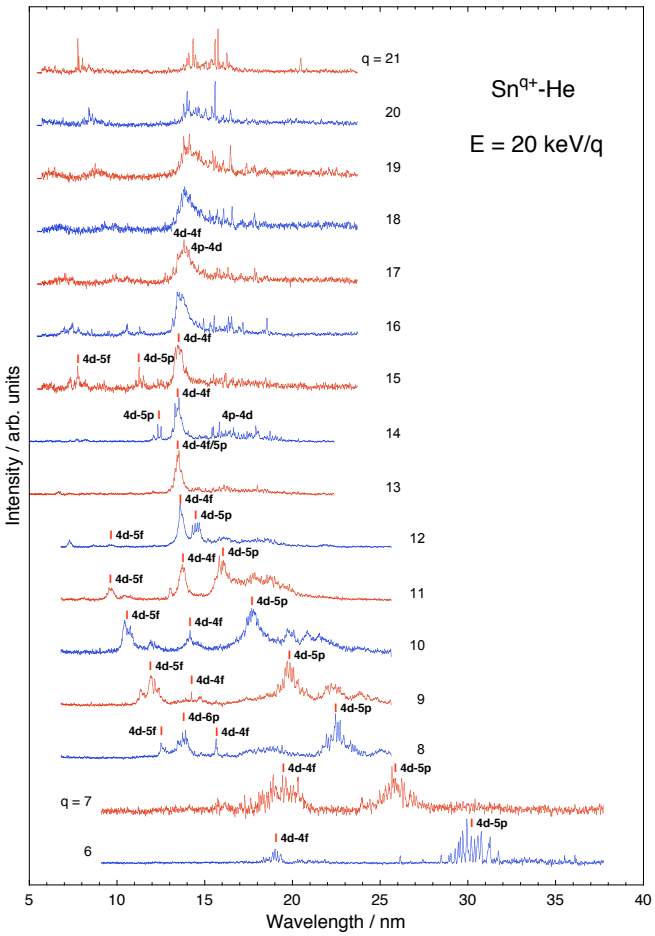
Out-Of-Band Emission



VUV emission spectra in collisions of Sn^{5+} ions with He gas at 20 keV/q.

Most of the observed lines from 108 to 130 nm are corresponding to the 5s-5p transitions of Sn V (Sn^{4+}). As the ground-state configuration of Sn V is $4d^{10}\ ^1S_0$, the transitions between excited states are observed in this spectrum.

In-Band Emission



EUV emission spectra in collisions of Sn^{q+} ($6 \le q \le 21$) ions with He gas at 20 keV/q.

Sn^{q+}	$Sn^{(q-1)+}$	$Sn^{(q-1)+*}$	Resonance lines
$3d^{10}4s$	$3d^{10}4s^2$	$3d^{10}4snl$	4s-*nl*
$4s^2$	$4s^24p$	$4s^2nl$	4p-*nl*
$4s^24p$	$4s^24p^2$	$4s^24pnl$	
$4s^24p^2$	$4s^24p^3$	$4s^24p^2nl$	
$4s^24p^3$	$4s^24p^4$	$4s^24p^3nl$	
$4s^24p^4$	$4s^24p^5$	$4s^24p^4nl$	
$4s^24p^5$	$4s^24p^6$	$4s^24p^5nl$	
$4p^6$	$4p^64d$	$4p^6nl$	4d-*nl*
$4p^64d$	$4p^64d^2$	$4p^64dnl$	
$4p^64d^2$	$4p^64d^3$	$4p^64d^2nl$	
$4p^64d^3$	$4p^64d^4$	$4p^64d^3nl$	
$4p^64d^4$	$4p^64d^5$	$4p^64d^4nl$	
$4p^64d^5$	$4p^64d^6$	$4p^64d^5nl$	
$4p^64d^6$	$4p^64d^7$	$4p^64d^6nl$	
$4p^64d^7$	$4p^64d^8$	$4p^64d^7nl$	
$4p^64d^8$	$4p^64d^9$	$4p^64d^8nl$	

Configurations of ground states of Sn^{q+} and $Sn^{(q-1)+}$ ions, and singly excited $Sn^{(q-1)+}$ ions

Discussion

- The charge states of emitting Sn ions are considered to be (q-1)+ because the single electron capture is generally the most dominant in collisions with He.
- VUV spectra corresponding to the out-of-band emissions can be observed with the same principle of the EUV measurements.
- EUV spectra consist of resolved lines and UTAs (unresolved transition arrays).
- Charge state dependence in higher ionization stages is not so strong, but spectra significantly depend on the charge state in lower ionization stages.
- Not only resonance lines, transitions between excited states have significant contribution in both the VUV and EUV emission spectra.

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